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# INVESTIGATION OF ELECTRON SPECTRA IN THE EARTH'S INNER RADIATION BELT BY THE SATELLITE KOSMOS 219

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# INVESTIGATION OF ELECTRON SPECTRA IN THE EARTH'S INNER RADIATION BELT BY THE SATELLITE KOSMOS 219

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ABSTRACT. Measurements of electron spectra made in April 1968, and a comparison with the 1962-1966 experiments, trace the change in the shape of electron spectra in the inner belt. Observed was a 1968 separation of the electron spectrum into two components: soft ($E \lesssim 0.8$ MeV) and hard ($E > 0.8$ MeV). Integral and differential spectra of electrons with E = 0.12 - 15 MeV on L = 1.2 - 1.8, and the spatial distribution of the electrons in the inner belt, are cited.

The high-altitude nuclear burst, Starfish, on 9 July 1962, definitely /890* complicated the investigation of the electrons in the inner belt because the electrons injected by the burst dominated the electrons attributable to all other possible sources for several years. The relatively few experiments designed to investigate electron spectra, and carried out prior to the burst, failed to provide a complete picture of the status of the electron component of natural origin.

The 1967-1968 experiments are of interest primarily because they make it possible to trace the behavior of the electron component injected by the Starfish burst, and to investigate electrons of natural origin in certain of the L shells where, up to this point, the preburst distribution has prevailed.

The satellite Kosmos 219 was launched on 26 April 1968. Its orbit had an apogee of ~ 1750 km, a perigee of ~ 200 km, and an inclination to the plane of the equator of ~ 49°. It carried a number of detectors for use in investigating the electron spectra in the energy range from ~ 0.13 to 15 MeV.

Figure 1 shows the distribution of electron fluxes of approximately the same energy measured in December 1964 (1) by the satellite 1964-45 A [1], and in April 1968 (2) by the satellite Kosmos 219. Included as well (3) is the electron distribution measured prior to the burst, in August 1961, by Explorer 12 [2].

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* Numbers in the margin indicate pagination in the foreign text.

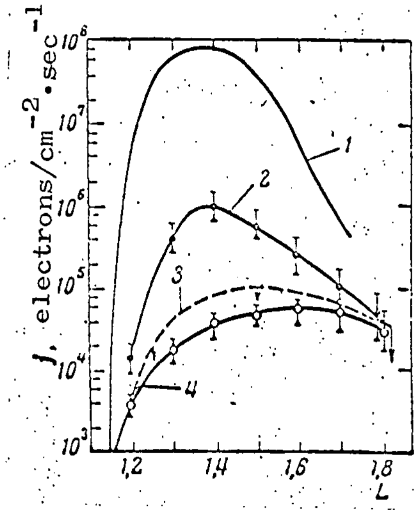


Figure 1. Distribution of electron fluxes with energies of $E_e \gtrsim 1.5$ MeV. 1 - December 1964; 2 - April 1968; 3 - August 1961 (prior to Starfish burst); 4 - distribution of proton flux with $E_p > 20$ MeV in April 1968.

The counter carried by Kosmos 219 had specially selected shielding equivalent to that provided for the GM-302 counter carried by Explorer 12. Both counters could register electrons with $E_e \geq 1.5$ MeV and protons with energies of $E_p \gtrsim 20$ MeV. This distribution too is shown in the figures as (4). Note that by April 1968, the preburst distribution of electrons on L < 1.2 and L ≥ 1.7 was established, and that the intensities of the artificial electrons in the center of the belt exceeded the preburst level by a factor of from 5 to 10. Note too that the decay of the belt takes place on the small L side, where the influence of the atmosphere is substantial and the lifetime is determined by the interaction with the atmosphere, as well as on the large L side, where particle lifetime is limited by different mechanisms with different natures (scattering by electromagnetic waves, different types of instability, and the like) [3]. Evidently it was not until the end of 1970 that the distribution of electrons attributable to natural processes was established throughout the inner belt, with conservation of the lifetime of the artificial electrons at the level of ~ 1 year. /891

Figure 2 shows the integral spectra of the electrons in the inner belt, obtained by Kosmos 219 in April 1968. The first two points with energies $E_e > 130$ keV and $E_e > 400$ keV were obtained by a scintillation counter with a plastic scintillator. Gas discharge counters with different shielding were used to obtain the point with energies $E_e > 700$ keV and $E_e > 1.5$ MeV. Correction factors for the effect of protons and bremsstrahlung were applied to the counter /892 readings. The intensities of the proton component were measured by this satellite with a proton spectrometer. Data on the electron fluxes with $E_e > 2.5$ MeV were obtained from ionization chamber readings, and here too the effect of protons was taken into consideration. Finally, the points with energies $E_e > 7$ MeV and $E_e > 15$ MeV were obtained from the Cherenkov detector readings. These points are shown by the down arrows, and are the upper limits for the electron fluxes of the energy indicated because these same channels can register proton fluxes with energies of $E_p > 600$ MeV and $E_p > 1000$ MeV [4]. A special analysis was made of the relationships between intensities on the basis of longitude, and the results were compared with the data in reference [5], which dealt with protons with $E_p \gtrsim 400$ MeV. It was found that the contribution of the electrons was very significant, and can be as much as ~ 80 percent of the total detector count.

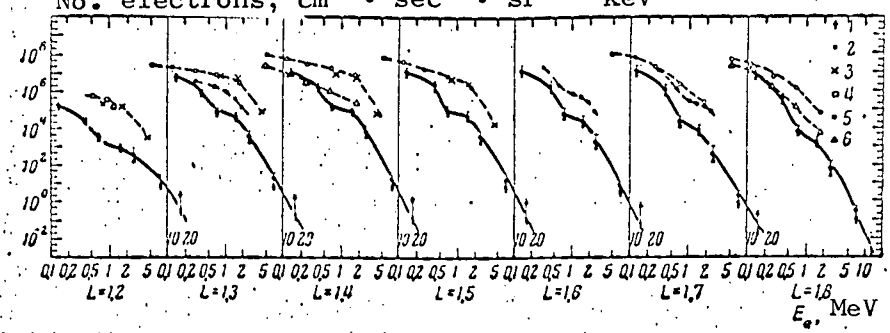


Figure 2. Integral spectra of electrons in the equatorial plane on different L shells, obtained in April 1968, and in earlier experiments. 1 - Kosmos 219; 2 - 1966-70 A; 3 - 1964-45 A; 4 - Elektron; 5 - OGO-1; 6 - OGO-3.

This same figure shows data from earlier experiments, such as the OGO-1 (September 1964) [6], the OGO-3 (October 1966) [7], the 1964-45 A (November 1964) [1], Elektron (February 1964) [8], and the 1966-70 A (August 1966) [9].

A characteristic feature of the 1968 electron spectra is the separation of the spectra into two components: soft, with energies to > 0.7 MeV. It is our opinion that the difference between the 1964-1966 spectra and the 1968 spectra is attributable to the fact that the low-energy part ( < 400 keV) remained practically constant after 1966, in that year reaching some level determined by natural processes. The high-energy part ( > 700 keV) continued to decrease to a lifetime of ~ 300 days, retaining approximately the same spectrum shape. At the same time, the boundary between the "natural" and the "artificially injected" parts of the spectrum shifted to the high energy side.

The last point in the spectra ($E_e$ > 15 MeV) usually is not plotted on the curve approximating the high-energy part of the spectrum. The approximation therefore was made without taking this last point into consideration. It is possible that the energy threshold of registration of electrons is somewhat exaggerated and is ~ 10 MeV. Concordance would be better in such case.

The section of the spectrum for $E_e$ < 0.7 MeV becomes markedly softer with increase in L, and can be approximated by exponential distributions with characteristic energy $E_0'$ = 0.08 - 0.15 MeV. The hard component has a characteristic energy of $E_0$ = 0.7 - 0.8 MeV.

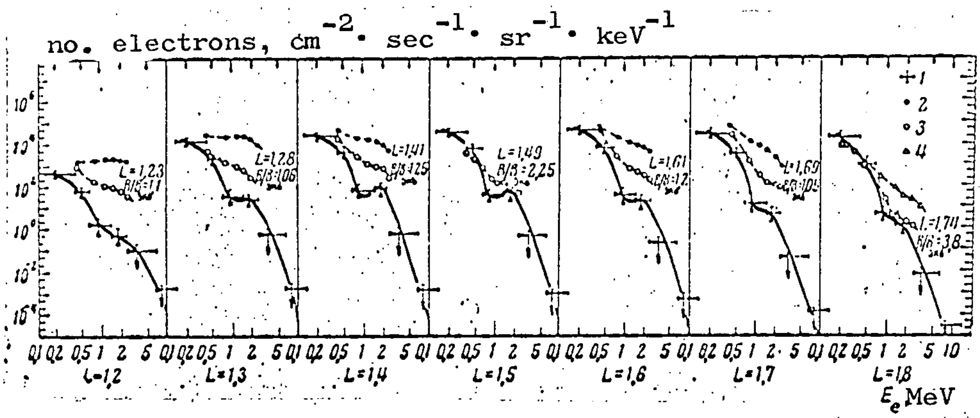


Figure 3. Differential spectra of electrons in the equatorial plane on different L shells, obtained in April 1968, and in earlier experiments: 1 - Kosmos 219; 2 - 1962-βK; 3 - 1966-70 A; 4 - 1964-45 A.

Figure 3 shows the differential electron spectra in the equatorial plane on shells with values L = 1.2 - 1.8, measured by Kosmos 219 in April 1968. Also shown are the results of earlier experiments for approximately the same L values near the equatorial plane. The information from all these data make it possible to trace the dynamics of the decay of the electrons in the inner belt, and of certain of the changes in the shape of the electron spectra over the period 1962-1968. Some difference in the magnitude of the $B/B_{eq}$ ratio is of no moment because the shape of the electron spectrum is not greatly dependent on this ratio.

As will be seen from Figure 3, the intensities of some of the energy ranges changed by a factor of from 100 to 1000, between 1962 and 1968, and were incomparably weaker, by a maximum of a factor of 10, at energies < 0.4 MeV.

The change in the shape of the spectra between 1962 and 1968 can be characterized by:

1. an initial distribution of electrons with a quite flat differential spectrum, with a decay at energies $\sim$ 2 MeV;

2. some flattening of the differential spectra in the energy field between 0.5 and 1 MeV between 1964-1966. The change in the spectrum was more rapid at lower and higher energies. Separation of the spectrum into two components was noted at comparatively large L. The high energy part of the spectrum ($E_e$ = 1 - 2 MeV), attributable to the ejection of electrons as a result of the Starfish burst, changed shape very little over the period (similar results were obtained in reference [10]); /893

3. a clear separation of the electron spectrum in the whole of the inner belt into two components by 1968: soft ($E_e$ < 0.8 MeV); and hard ($E_e$ > 0.8 MeV). This separation occurred because the intensities of the electrons in the energy range $\sim$ 0.1 - 0.8 MeV apparently had begun to be determined by certain natural processes yielding spectra with rapid decay to energies $\sim$ 0.8 MeV, while the intensities of electrons with energies > 0.8 MeV still were determined to a considerable degree by the electrons from the Starfish burst, and can be characterized by comparatively high energies and quite high values for characteristic energy, $E_0 \sim$ 1 MeV.

In 1968, the boundary between the natural electron distribution and the high energy electrons from Starfish was close to $\sim$ 0.8 MeV. Spectrum separation was sharper in the center of the artificial belt of electrons (L = 1.3 - 1.5).

With the results of Figure 1 in mind, and from which it follows that the preburst distribution of electrons with $E_e$ > 1.5 MeV has been established on L < 1.2 and L ≥ 1.7, one can conclude that the types of spectra on L = 1.7 and L = 1.8 are close to the spectra attributable to natural processes over the whole of the range of energies. (The electron spectrum on L = 1.2, when energies are ~ 5 - 10 MeV, should decay more rapidly because the influence of protons with energies ~ 600 MeV is particular great on L = 1.2). Nevertheless, seen on L = 1.7 - 1.8 is the characteristic discontinuity in the spectrum, determined by the fact that the decay in the intensities of the high energy electrons ($E_e \gtrsim 1$ MeV) takes place in accordance with another law.

These lead to the assumption that the spectrum of electrons of natural /894 origin is formed as a result of the actions of several mechanisms:

(a) the $\beta$-decay of slow neutrons of the cosmic ray albedo determines the electron intensity and the rapid decay of the electrons near the boundary energy of $\beta$-decay (~ 780 keV);

(b) some mechanism ensuring the injection of electrons in the range < 0.4 MeV should be acting below ~ 400 keV, where decay into a differential electron spectrum the result of the $\beta$-decay of neutrons should be observed. This mechanism can be the injection of electrons with energies of several tens to hundred of keV, followed by diffusion in the inner belt during strong magnetic storms. This mechanism obviously is the determinant in the formation of the section of the spectrum from ~ 0.1 to ~ 0.5 MeV [11]. The lifetimes of these electrons are long, and one or two strong perturbations a year are all that are necessary to maintain the intensity of the electrons at a quasistationary level;

(c) because the injection of electrons with energies $E_e > 1.0$ MeV into the inner belt has not been observed during magnetic storms, the existence of some additional mechanism providing for the injection of electrons with $E_e > 1$ MeV can be assumed. The effect of this mechanism is to cause the appearance of a higher energy component. The $\beta$-decay of fast neutrons [12, 13], or the diffusion of electrons from the region with higher L values to the earth [3], can be such a mechanism.

Thus, the electron spectrum in the inner belt can be the superposition of several spectra formed by the actions of different mechanisms. On the L shells, where the influence of the artificially injected electrons is substantial, the appearance of the spectrum also will be determined by the equilibrium $\beta$-spectrum of the decay of fission fragments of the thermonuclear burst. This is shown schematically in Figure 4, where the role of the different mechanisms in the formation of the electron spectrum in the inner belt is shown.

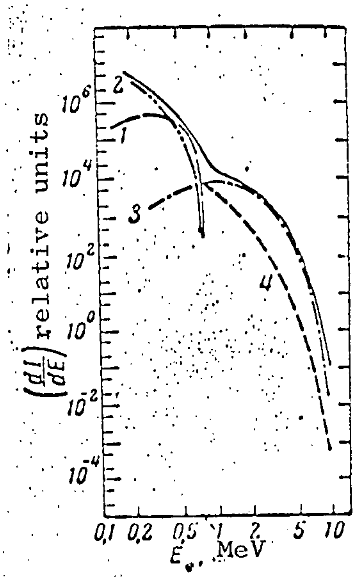


Figure 4. A possible explanation of the role of the different mechanisms in the formation of the electron spectra in the inner belt (see text for explanation).

Curve 1 in Figure 4 depicts the electron spectrum from the β-decay of slow neutrons. Curve 2 is the spectrum of electrons injected into the inner belt during strong magnetic storms. Curve 3 is the equilibrium spectrum of the β-decay of fission fragments from the Starfish burst, and curve 4 is the spectrum of the high energy component of the inner belt electrons resulting from natural processes.

The solid curve is the spectrum that results when these spectra are superposed. It resembles, in appearance, the spectrum measured on L = 1.3 (Figure 3). The high energy component should follow curve 4 in the case of large L values, and then it is possible to obtain spectra similar to those measured on L = 1.7 and L = 1.8.

Redistribution of the relative influence of each of the spectra on the different L shells, and change in the shape of the original spectra with L, can transform the appearance of the spectrum somewhat, giving it more, or less, of a discontinuity, changing the hardness of the individual sections of it with change in L, and the like.

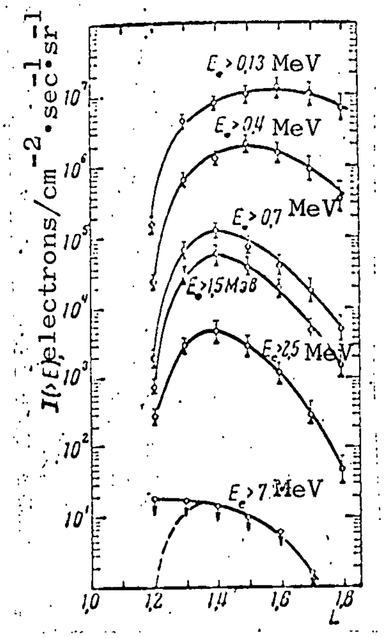


Figure 5. Spatial distribution of electrons of different energies in the equatorial plane in April 1968. The dashed line indicated the assumed distribution of electrons with $E_e > 7$ MeV on $L < 1.3$.

Figure 5 shows the spatial distribution of electrons with different energies in the equatorial plane in April 1968, according to the data from Kosmos 219. Since the Cherenkov detector readings on the shells with $L < 1.3$ were determined primarily by protons with energy $E_p > 600$ MeV, the dotted curve indicates the assumed distribution of electrons with $E_e > 7$ MeV on $L < 1.3$.

Electrons of natural origin have distribution maxima on $L \sim 1.6$ (for $E_e > 0.13$ MeV), and on $L \sim 1.5$ (for $E_e > 0.4$ MeV), whereas electrons of artificial origin have a distribution maximum at what is practically the same value, $L \sim 1.35$, for all energies.

The measurements of the intensities of electron fluxes in April 1968, were made during a geomagnetically quiet period, so the following values of maximum intensities of electrons of natural origin in the inner belt can be considered typical: $I(> 0.13 \text{ MeV}) \sim 10^7$ electrons/cm$^{-2}$• sec$^{-1}$• sr$^{-1}$; $I(> 0.4 \text{ MeV}) \sim 2 \cdot 10^6$ electrons/cm$^{-2}$• sec$^{-1}$• sr$^{-1}$; $I(> 0.7 \text{ MeV}) \sim 10^5$ electrons/cm$^{-2}$• sec$^{-1}$• sr$^{-1}$; $I(> 1.5 \text{ MeV}) \sim 10^4$ electrons/cm$^{-2}$• sec$^{-1}$• sr$^{-1}$ (curve 3 in Figure 1). O'Brien's estimates [14] of maximum electron fluxes perpendicular to the lines of force /895 agree well with these data: $I_{\perp}$ (> 0.04 MeV) $\approx 10^8$ electrons/cm$^{-2}$ · sec$^{-1}$ · sr$^{-1}$; and $I_{\perp}$ (> 0.6 MeV) $\approx 10^6$ electrons/cm$^{-2}$ · sec$^{-1}$ · sr$^{-1}$.

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